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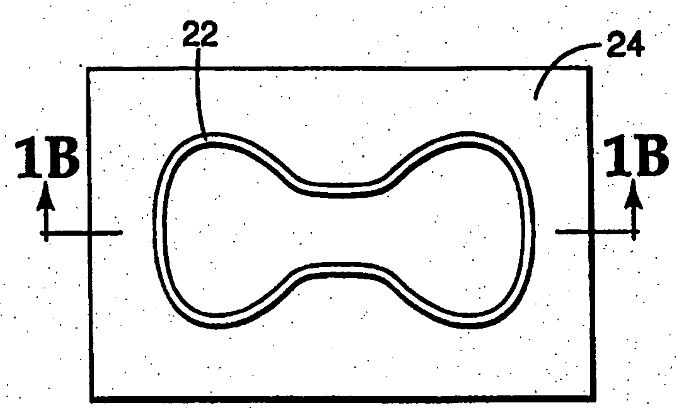
(54) Title: METHOD FOR LOCALLY HEATING A WORK PIECE USING PLATENS CONTAINING RF SUSCEPTORS

(57) Abstract

The present invention is a method for locally heating a work piece, which includes the initial step of forming a platen (22) from a composite (10) comprising RF susceptor particles (12) dispersed in a non-metallic matrix (14). An electromagnetic field is then applied to the platen (22) to heat the platen (22) to a predetermined processing temperature, and the work piece is positioned proximate to the platen (22). The present invention also is directed to an apparatus for locally heating a work piece, which includes a platen (22) formed from a composite (10) comprising a matrix (14) and susceptor particles (12) dispersed in the matrix (14), a means for remotely applying an electromagnetic field to the platen (22), and a means for positioning the work piece proximate to the platen (22).



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METHOD FOR LOCALLY HEATING A WORK PIECE USING PLATENS CONTAINING RF SUSCEPTORS

Field of the Invention

The present invention relates generally to a process for the localized heating of a work piece using a platen or die. More particularly, the localized heating process of the present invention uses a platen made of a composite comprising radio frequency (RF) susceptor particles dispersed in a non-metallic matrix. When placed adjacent a work piece and exposed to electromagnetic energy, the platen heats to a sufficient temperature to emboss a work area of the work piece or bond a desired portion of the work piece to another article.

Background of the Invention

It is desirable for a variety of applications to locally heat a material in a specific area, or to bond the material to the same or a different material in a predetermined pattern. The localized heating is often desired only in certain patterns across the surfaces of the material. To provide this patterned application of heat, a metal platen is machined, heated, and placed in contact with the material to bond, seal, and emboss along the bond contours.

It is known in the art to bond objects such as layers of films, sheets, nonwovens, or combinations thereof by applying localized heat from a platen or a die. The platen is typically heated by resistance or induction heating. For example, U.S. Pat. No. 4,268,338 (Peterson) describes a method of bonding sheets of thermoplastic material in which a conductive electrode die is heated by an RF current and applied to the thermoplastic surfaces to be joined. The face of the die was machined so that only those areas to be bonded were heated to a sufficient temperature to form a seal. One problem with such a technique is that the fabrication of a suitable conductive die or platen is often time consuming and costly, especially when the bonding contour is particularly complex or intricate. These concerns are multiplied when the application requires frequent changes or minor alterations in the design of the bonding contour. In such cases, a separate die or platen must be fabricated for each specific bonding contour desired. This

increases cost and reduces the efficiency of the bonding process. The resistance or induction heating of the die also requires a relatively large amount of power.

In addition to the direct induction and resistance heating methods described above, it is also known to apply localized heat to a material using remote application of RF energy. In these processes, materials in the material absorb electromagnetic power and convert the absorbed energy to heat *in situ*. These processes are highly efficient and generally use much less energy than inductive or resistance heating techniques.

For example, U.S. Pat. No. 3,620,876 (Guglielmo) teaches that ferromagnetic particles may be dispersed within a liquid adhesive. When the loaded adhesive is placed between two articles to be bonded and exposed to an RF field, the ferromagnetic particles increase in temperature and heat the adhesive to bond articles together. WO 93/11926 teaches that an RF-active coating may be selectively applied between film layers and heated to bond the layers together in specific areas. If two films are to be bonded together, the RF-absorbing particles may also be incorporated into at least one of the films in selected areas.

In a bonding method described in copending and co-assigned U.S. Application No. 08/412,966, layered flakes comprising a ferromagnetic material are dispersed in a binder to form an electromagnetic power absorbing composite. The objects to be bonded are then placed adjacent one another and in direct contact with the composite. Electromagnetic power is then applied to the composite material to heat the composite to a temperature sufficient to bond the objects together by melting, fusing, or adhesive curing.

In all the above-described bonding methods in which heat is generated by the remote application of RF energy, the RF-active material is either in the form of a coating, adhesive, or binder that is placed in direct contact with each of the articles to be joined, or the RF-active material itself is incorporated into one of the materials to be joined. In each case, upon bonding, the RF-active material necessarily remains with the bonded articles as a permanent agent of the bond. As such, with each bonding application, additional amounts of the RF-active material are required, thus incurring additional costs.

If the RF-active material could be removed from the articles to be bonded, and the heat produced by the RF-active material selectively applied to specific areas of the article with low tooling costs, the energy efficiencies of the processes in which RF energy is remotely applied could be more effectively exploited to commercial advantage.

Summary of the Invention

The present invention is a method for locally heating a work piece, which includes the initial step of forming a platen from a composite comprising RF susceptor particles dispersed in a non-metallic matrix. When exposed to an alternating electromagnetic field, RF susceptor particles absorb energy and heat the platen. The work piece is then positioned in contact with the platen for a time sufficient to process the work piece.

The present invention also is directed to an apparatus for locally heating a work piece, which includes a platen formed from a composite comprising RF susceptor particles dispersed in a matrix, a means for remotely applying an electromagnetic field to the platen, and a means for positioning the work piece in contact with the platen.

The platen used in the process of the present invention may be made of a matrix material which is easily formed in a mold to provide localized heating in a precisely patterned work area on the work piece. The moldability of the matrix material makes it much more adaptable to changing work area geometries than metal platens, and an operator may easily modify the pattern in which the heat is applied to the work area. The platen of the present invention may be used and re-used many times, and there is no need to incorporate the RF susceptor particles into the work piece material itself to provide localized heating in the work area. Platens loaded with efficient susceptor particles (such as those in the preferred embodiment of the present invention as described hereinafter) consume less power compared to traditional inductively heated platens. Compared to resistively heated platens, platens loaded with susceptor particles heat in a much more

uniform fashion because the susceptors distribute the heat throughout the matrix that forms the platen.

The matrix material in which the RF susceptor particles are imbedded can be any non-metallic material capable of sustaining a temperature sufficient to process the work piece. The susceptor particles may be ferrimagnetic or ferromagnetic particles that can absorb electromagnetic energy and efficiently convert the absorbed energy to heat. In the preferred embodiment, the susceptor particles are multilayered flakes comprising at least one layer pair, each layer pair comprising one thin film crystalline layer of ferromagnetic metal adjacent to one thin film layer of dielectric material. The ferromagnetic metal preferably comprises a NiFe alloy.

Brief Description of the Drawings

Figure 1A is a schematic representation of an arbitrarily-shaped platen of this invention.

Figure 1B is a schematic cross-sectional side view of the platen of Figure 1A taken along line 1B.

Figure 2 is a schematic cross-sectional view of electromagnetic-power-absorbing particles dispersed in a matrix that comprises the platen of this invention.

Figure 3 is a schematic cross-sectional view of a multilayered flake contained in one embodiment of the platen of this invention.

Figure 4 is a schematic representation of one embodiment of the method of bonding thermoplastic layers of this invention.

Figure 5 is a plot of temperature versus exposure time data obtained for platens of this invention comprising various types of susceptor particles as listed in Table 1.

Detailed Description

The term "radio frequency," or "RF," as used herein refers to electromagnetic energy in the radio frequency band which, according to the

McGraw-Hill Dictionary of Scientific and Engineering Terms, includes those frequencies between 10 kHz and 1000 GHz. Thus, a material is said to be "RF-active" if it absorbs energy from an alternating electromagnetic field in the RF frequency band as defined. Moreover, the terms "susceptor particles," "RF susceptors," and "RF susceptor particles" as used herein refer to particles that are RF-active.

In the localized heating method of the present invention, a platen 22 is provided as shown in Figure 1A and in cross-section in Figure 1B. The platen 22 is heated by remotely applying an electromagnetic field. When the platen is heated to a pre-determined temperature, it is placed in contact with a surface of a work piece for a pre-determined amount of time to emboss a work area of the work piece or bond the work area or a portion thereof to a second work piece. The platen may be shaped such that only specific work areas of the work piece are acted on by the platen.

In Figure 1A, the platen 22 has a generally dumbbell-like shape. However, the platen 22 may be made in any shape suitable for a particular bonding or embossing application. The platen 22 is preferably mounted on a support plate 24 which provides a rigid backing for the platen and ensures that uniform pressure and consequently uniform heating are applied to the work areas of the work piece. It is desirable that the support plate be composed of a material that is a poor conductor of heat so that the support plate will not conduct heat away from the heated platen. An example of a preferred material for the support plate is a glass bead-filled epoxy.

The platen of the present invention is molded or otherwise fabricated from a composite 10 as shown in Figure 2. The composite comprises RF susceptor particles 12 dispersed in a binder or a matrix 14. The matrix 14 is acted upon by heat generated within the composite 10 due to the interaction between the applied electromagnetic field and the susceptor particles 12. This heating brings the platen to a desired temperature. The matrix 14 and the RF susceptor particles 12 are chosen for their suitability in a particular bonding or embossing application, as described below.

The composite 10 is preferably sufficiently nonconductive so that at least a portion of an applied electromagnetic field is absorbed by the susceptor particles for conversion to heat. With respect to conductivity, the dielectric loss tangent, $\varepsilon''/\varepsilon'$, of the composite is preferably sufficiently small so that the skin depth of the composite for the applied field is greater than or equal to the thickness of the composite itself. The imaginary, or "lossy", portion of the relative magnetic permeability of the composite used to make the platen, μ'', is preferably maximized at the desired frequency to realize the highest energy-to-heat conversion efficiency. The value of μ'' for the composite material of the platen has generally been observed to be about 0.05 to about 10 for the frequency range of about 100 kHz to about 6000 MHz. The value of μ'' is desirably at least about 0.1 at the frequency of power absorption., and may be measured using a strip line cavity as described in the following reference: R.A. Waldron, Theory of Strip-Line Cavity Measurements of Dielectric Constants and Gyromagnetic-Resonance Linewidths, IEEE Transactions on Microwave Theory and Techniques, vol. 12, 1964, pp. 123-131.

The matrix material is selected for a particular application based on its stability in the appropriate temperature range required to heat a work area of the work piece, its amenability to formation into an appropriate shape corresponding to the contour of the work area on the work piece, its compatibility with respect to the material composition of the work piece, and other properties of concern such as its strength, elasticity, and durability. The matrix 14 may be selected from any material stable at the temperature required to emboss, bond, or otherwise process the work piece, and should be sufficiently nonconductive so that at least a portion of the applied electromagnetic field will be absorbed by the RF susceptor particles in the composite for conversion to heat in the platen. Examples of matrix materials which may be suitable for use in the composite of the present invention include, for example, epoxies, polytetrafluoroethylene (available under the trade designation Teflon from DuPont, Wilmington, DE), fluoroelastomers, phenolic resins, ceramics and other non-metallic materials.

In addition, common filler materials, powders, or additives may be added to the matrix material to produce desired physical properties in the composite such as flexibility, durability, elasticity, or mechanical strength or to promote cure reactions during molding of the matrix material if the matrix material is of a type that requires curing. The addition of relatively small amounts of such property-enhancing fillers and additives is known, and it will be obvious to one of ordinary skill what, if any, additives and fillers may or should be employed once a matrix material is chosen for the particular application.

To join, seal, or emboss a work piece comprising one or more thermoplastic films or nonwovens, for example, a preferred matrix material for the platen of the present invention is a fluoroelastomer. These materials are stable at temperatures up to about 260 °C, and so are adequate for bonding most thermoplastics. The fluoroelastomers are easily formable into any arbitrary shape to heat a work area in any desired pattern. A particularly preferred matrix material for the platen of the process of the present invention is a high temperature fluoroelastomer available from Dyneon Corp., St. Paul, MN under the trade designation Fluorel.

The RF susceptor particles 12 are mixed or blended with the matrix material to make the composite that forms the platen. The susceptor particles may be any RF-active particles that absorb RF electromagnetic energy and transform it into heat. The susceptor particles preferably comprise an RF-active ferromagnetic or ferrimagnetic material that generate heat when exposed to electromagnetic fields in the RF range. More preferably, the susceptor particles generate heat upon absorption of electromagnetic energy with a frequency between about 100 kHz and about 6000 MHz, and most preferably, between about 50 MHz and about 2500 MHz.

Ferrite particles such as those described in U.S. Pat. No. 5,317,045 (Clark, Jr.) may be used as the susceptor particles in the platen of the process of the present invention. Ferrites are generally defined as certain double oxides of iron and other metals, and are described in well-known references such as B.D. Cullity, Introduction to Magnetic Materials (Addison-Wesley Publishing Co., Reading,

Mass., 1972), and E.P. Wolfarth, Ferromagnetic Materials, volume 2. Ferrites are ferrimagnetic, which refers to a phenomenon in some magnetically ordered materials in which there is incomplete cancellation of the antiferromagnetically arranged spins giving a set magnetic moment--the equivalent behavior in a nonmetal to ferromagnetism in metals (See, e.g. Academic Press Dictionary of Science and Technology, Morris, C., ed. (1992).). Ferrimagnetism results from a different type of ordering of magnetic moments than in ferromagnetism. The ferrimagnetic ordering occurs when the interactions of magnetic ions in a crystal unit cell are mediated by the presence of non-magnetic ions.

If ferrite particles are used, an oscillating magnetic field in the upper portion of the RF frequency range (i.e. 300 MHz to 1000 GHz, also referred to in the art as the microwave frequency band) may be coupled to perpendicularly oriented magnetic spins in the particles dispersed in the absorbing matrix of the platen composite. The ferrite particles are preferably made from double oxides of iron with nickel, zinc, copper, manganese, magnesium or combinations thereof. The ferrite particles are typically substantially spherical in shape, and for use in the present invention preferably have diameters of about 0.5 μm to about 50 μm. Ferrites are manufactured by known techniques used to manufacture ceramics. For example, NiO and Fe_2O_3 can be mixed in powder form, pressed into a desired shape, and sintered at a temperature of 1200 °C or greater. The resulting ceramic is brittle and can be ball milled to form ferrite particles. Ferrites are also commercially available from many sources such as Steward, Inc., Chattanooga, TN.

Ferrites, however, have some disadvantages for the present application. For example, the maximum permeability of ferrites is limited relative to that of metal alloys. The generally spherical shape of the particles make them difficult to form into particles having a thin needle or plate-like shape to allow efficient penetration of the magnetic field. As a result, the magnetic field tends to become depolarized in the ferrite particle, thereby limiting the bulk permeability of the absorbing material and the overall energy-to-heat conversion efficiency.

Ferromagnetic particles are preferred for use as susceptor particles in the platen in the process of the present invention. The Academic Press Dictionary of Science and Technology defines ferromagnetism as a phenomenon that is exhibited by certain metals and alloys (particularly those of the iron group, rare earth and actinide series) in which the atomic magnetic moments are capable of spontaneous magnetic polarization resulting in significant magnetic effects. Relative magnetic permeabilities of such materials range from about 1.1 to 10^6. The defining characteristic of ferromagnetic materials is that the atomic magnetic moments tend to line up in a common direction. Ferromagnetic and ferrimagnetic substances can be distinguished from one another by magnetic measurement only if the measurements extend over a range of temperature.

The ferromagnetic particles most preferred for use in the present invention are the layered flakes described hereinafter and in the copending U.S. Application Serial No. 08/412,966. As shown in Figure 3 of the present application, each of the layered flakes 20 comprise at least one layer pair, each layer pair comprising one thin film crystalline ferromagnetic metal layer 16 adjacent to one thin film dielectric layer 18. As used herein, crystalline means that the atoms comprising the grains of the thin film ferromagnetic layers are packed in a regularly ordered array having an identifiable structure. Also, as used herein, a thin film is a coating whose thickness is preferably less than about 10 micrometers.

Figure 3 shows a flake 12 having two layer pairs. If the flakes have two or more layer pairs, the layer pairs form a stack of alternating ferromagnetic metal layers 16 and dielectric layers 18. Typically, a dielectric layer 18 comprises both of the outermost layers of the stack, as shown in Figure 3. The flakes are randomly dispersed in the matrix, although the flakes may be preferably oriented so that the plane of the thin film layers is substantially parallel to the plane of the platen.

The flakes have a maximum major dimension in the plane of the thin film layers which is preferably about 25 μm to about 6000 μm. The flake sizes of a plurality of flakes generally occur in a distribution extending from the maximum major dimension to substantially zero. The size distribution of the flakes may be

altered by the process used to disperse them in the matrix material. The thickness of the flakes, i.e., the dimension perpendicular to the plane of the thin film layers, may be chosen to suit a particular application. The ratio of the flake thickness to the maximum major dimension is typically from about 1:6 to about 1:1000, indicating a flake which is relatively plate-like in shape. This ratio allows a magnetic field oriented in the plane of the flakes to penetrate the ferromagnetic metal layers readily with minimal depolarization. This ratio also leads to a relatively high proportion of surface area to volume of the flakes in the matrix, facilitating efficient transfer of heat from the flakes to the matrix.

The number of layer pairs in each flake is preferably in the range from about 2 to about 100, most preferably about 10 to about 75. Using flakes with relatively fewer layer pairs (resulting in thinner flakes) may require adding a greater number of flakes to the composite in order to provide sufficient ferromagnetic metal for conversion of electromagnetic energy to heat. Using thinner flakes also tends to increase the ratio of surface area to volume of the flakes in the matrix, which may improve the efficiency of thermal transfer from the flakes to the surrounding matrix. Unlike other known absorbing composites, the number of layer pairs in the flakes may be fewer than what is required to provide a quarter-wave absorbing stack, since the flakes provide power absorption by conversion to heat through magnetic resonance rather than by phase interference.

Alloys for the ferromagnetic layers of the flakes may be chosen to provide a material in which the rate of heating within the material will go essentially to zero as the temperature rises to a critical level (i.e., a heat-limiting material). In this way, overheating of the material may be prevented. The loss of heating above the critical temperature is due to the drop in the permeability of the alloy. The ferromagnetic metal layers in the flakes preferably comprise a crystalline ferromagnetic metal alloy having an intrinsic direct current (DC) permeability of at least 100 relative to free space. Amorphous alloys can be used but are less desirable because of their greater cost to obtain and process. The alloy used in the ferromagnetic layers preferably comprises NiFe containing at most about 80% by weight Fe, more preferably about 20% Fe. The alloy may also include other

magnetic or nonmagnetic elements such as Cr, Mo, Cu, and Co, as long as the alloy remains magnetic. Different ferromagnetic metal layers in the same flake may comprise different alloys.

The thickness of ferromagnetic metal layer 16 is preferably about or less than a skin depth for the electromagnetic power applied to the composite for the power to couple efficiently with the magnetic atoms in the layer, while being of sufficient thickness so that adequate electromagnetic energy is converted to heat for a particular application. Skin depth of a material is defined as the distance into that material at which the magnitude of an applied magnetic field drops to 37% of its free space value. For example, the thickness of each ferromagnetic metal layer 16 is preferably in the range from about 10 nm to about 500 nm, and more preferably about 75 nm to about 250 nm, in the case where the ferromagnetic metal layer 16 comprises $Ni_{80}Fe_{20}$ and electromagnetic power frequency is in the range from 100 kHz to 6000 MHz. Skin depth is an inverse function of the frequency of the applied field. Therefore, the application of electromagnetic power at the low end of the above-described frequency range enables the use of relatively thicker ferromagnetic metal layers. The thickness of the ferromagnetic metal layer may be optimized to minimize the number of layer pairs in the flake, which is economically desirable.

Dielectric layers 18 may be made of any known relatively non-conducting dielectric material which is stable at the temperatures the flakes will be expected to reach in a particular application. Such materials include SiO, SiO_2, MgF_2, and other refractory materials, and also may include polymeric materials such as polyimides. The thickness of each dielectric layer 18 is in the range from about 5 nm to about 100 nm, and is preferably made as thin as possible while still ensuring adequate magnetic and electrical isolation of the ferromagnetic metal layers.

The flakes may be made by first depositing a stack of alternating ferromagnetic metal and dielectric layers of the desired materials on a substrate using a known thin film deposition technique, such as electron beam evaporation, thermal evaporation, sputtering, or plating. A preferred method uses electron beam evaporation in a conventionally designed vacuum system incorporating a

vacuum compatible web drive assembly, as described in U.S. Pat. No. 5,083,112. The substrate may be, for example, a polyimide, a polyester, or a polyolefin, and is preferably in the form of a flexible web. It is believed that magnetically orienting the ferromagnetic metal layers during deposition by applying an aligning magnetic field to the growing films in the cross web direction may be beneficial for some applications.

After a stack is produced having the desired number of layers, the stack may be removed from the substrate. An effective method of removal includes passing the substrate around a bar with the stack facing away from the bar, the bar having a sufficiently small radius such that the stack delaminates from the substrate. The stack may shatter into flakes having a suitable size as the stack is delaminating. Otherwise, the stack is then broken into flakes having a desired maximum size by a method such as grinding in a hammer mill fitted with an appropriately sized screen. In another method for making flakes, the stack of alternating layers may be deposited on a substrate which is the same as or compatible with the matrix to be used and the entire stack (including the substrate) is then broken into flakes.

The quantity of susceptor particles or flakes dispersed in the composite must provide an adequate amount of ferromagnetic or ferrimagnetic metal to generate sufficient heat in the composite at the desired frequency to process the work piece. Thus, generally speaking, if smaller ferrite particles (i.e., having relatively smaller diameters) or thinner flakes (i.e., having relatively fewer layer pairs) are used as susceptors, a larger quantity of those susceptors may be required. In the case of ferrite particles, the quantity of particles dispersed in the composite is preferably about 1% to about 30% by volume, and more preferably about 5% to about 20% by volume. In the case of ferromagnetic flakes, quantity of flakes dispersed in the composite is preferably about 0.1% to about 10 % by volume, and more preferably about 0.25% to about 5 % by volume. Mechanical properties of the composite may be affected by the quantity of flakes or particles, or by the thickness (i.e., number of layer pairs) of the flakes or diameter of the particles. Thus, generally speaking, if more flakes or particles are used or if larger

flakes or particles are used, the composite may fracture or fail more easily. If the frequency of the applied magnetic field is changed, the quantity of flakes or particles may also need to be adjusted accordingly to maintain a desirable heating efficiency. The composite is preferably not overloaded with susceptors, so that the susceptors are at least partially isolated electromagnetically from one another so as to inhibit eddy currents in the composite and allow electromagnetic energy at the susceptors to be converted to heat. Generally, complete flake or particle isolation is not required.

To produce the platen 22 shown in Figure 1A, the susceptor particles are dispersed in the matrix material by any suitable method and the resulting composite is formed into the desired platen shape. A specific thickness may be chosen to suit a particular application. The method of forming the platen from the composite will depend on the matrix material used. For example, a composite based on a fluoropolymer matrix material (or other curable polymer material) can easily be compression molded into a flat sheet and cut to a desired shape or compression molded directly into a desired shape. Similarly, a composite based on a ceramic matrix material can easily be formed and then fired under suitable conditions to produce a composite having the desired platen shape. It will be recognized by one of ordinary skill that the choice of a matrix material and the specific configuration of the platen will suggest what formation techniques are desirable. In a preferred embodiment, a platen is formed from a fluoroelastomer-based composite containing RF susceptor particles, compression molded, and cured to produce a platen with the desired shape.

Once the platen is formed into the desired shape it may be mounted to a support plate (as shown in Figures 1A and 1B) to provide added rigidity to the platen, especially for platens made from flexible composites or platens having intricate contours. The platen may be mounted to the support plate using any suitable means such as an adhesive or epoxy that is compatible with the composite. In a preferred embodiment, the fluoroelastomer-based platen is adhesively mounted on a support plate where the support plate is made from a

glass bead-filled epoxy. The glass bead-filled epoxy support plate helps to thermally isolate the platen to reduce heat loss and lower the power consumption.

In the process of the present invention, the platen is heated by exposure to electromagnetic energy and may thus be used to bond a first work piece to a second work piece in a specified area or contour, or to emboss one or more layers of a work piece. Figure 4 schematically illustrates a method for locally heating a work piece comprising two layers of a film-like material such as, for example, thermoplastic films, using a platen constructed as described above. Although the method represented by Figure 4 shows the bonding of two thermoplastic layers, the method for locally heating thermoplastic layers of the present invention is not limited to two layers. It will be recognized by one of ordinary skill that any number of thermoplastic layers may be locally heated using the method of the present invention, and that the number of layers is limited by the properties of the layers (i.e., thickness, melting temperature, etc.) and not by the method described herein nor by the platen described herein. In addition, it will be recognized by one of ordinary skill that the thermoplastic layers to be locally heated may include any combination of thermoplastic films or nonwoven materials made using thermoplastic fibers.

In Figure 4, a first thermoplastic layer 26 and a second thermoplastic layer 28 are drawn by rollers or other means into a region 30 that contains the platen 22. The first film 26 and the second film 28 are positioned with their respective surfaces to be joined adjacent to each other and substantially parallel to the plane of the platen 22. The platen 22 is heated by the application of an electromagnetic field in the region 30 such that the strength of the field is sufficient to heat the platen to a temperature at which the thermoplastic films may be bonded. In applying the electromagnetic field, it is desirable that the field in the plane of the platen be substantially uniform across the platen so that all areas will be heated to about the same temperature. In the preferred embodiment, the platen is contained inside a resonant cavity in which a magnetic field is applied. The resonant cavity is preferably designed to produce a substantially uniform magnetic field in the plane of the platen. The specific design and dimensions of the resonant cavity thus

depend critically on the dimensions and design of the platen. The design of a resonant cavity to apply a substantially uniform magnetic field across the platen will be apparent to one of ordinary skill in the art given the design and dimensions of the platen for a specific bonding or embossing application.

When the platen 22 is heated to the desired temperature, the platen and films 26 and 28 to be bonded are brought into close proximity so that the work areas of the surfaces to be bonded that are adjacent to the contours of the platen are heated and so the surface of the film closest to the platen is in contact with the platen. When contact is made, it is preferable to apply a moderate pressure between the platen and the films to achieve uniform contact and uniform heating over the work areas to be bonded. The applied pressure is preferably in the range of about 350 to about 3000 grams per square cm when a platen comprising a fluoropolymer matrix material is employed. The pressure required to achieve uniform heating may vary depending on the composition of the platen.

The platen and thermoplastic layers to be bonded may be moved relative to each other using any suitable means of moving the platen, the thermoplastic layers, or both. For example, the support plate may be mounted to any translation device so that the platen may be automatically moved toward and away from the thermoplastic layers, perpendicular to the plane of the platen. Alternatively, the thermoplastic layers may be moved toward the platen by positioning the thermoplastic layers on a platform, for example, located beneath the heated platen, wherein the platform is mounted to a translation device that may be automatically moved toward and away from the platen perpendicular to the plane of the platen. It is preferable to provide a means to move the thermoplastic layers toward the platen inside the resonant cavity so that the platen may remain stationary. The magnetic field in the plane of the platen should preferably remain uniform, but the magnetic field may change in intensity with distance in a direction perpendicular to the platen. Thus, to avoid changing the temperature of the platen by exposing it to higher or lower magnetic fields, it is preferable that the platen remain in a fixed position.

After a pre-determined time at a pre-determined temperature sufficient to bond the surfaces, the platen and thermoplastic layers are separated, and the thermoplastic layers are advanced onto take-up roll 30. When the thermoplastic layers are advanced in a step-wise fashion and the steps described above are repeated, the finished product is a continuous roll of thermoplastic layers locally bonded at periodic intervals.

In a preferred embodiment where the platen comprises ferromagnetic flakes dispersed in a fluoropolymer matrix at about 2.5% by volume, the platen is placed in the center of a rectangular resonant cavity having the dimensions about 51 cm × 38 cm × 17.5 cm, and an alternating magnetic field of frequency 913.8 MHz is applied at a power level of 200 Watts for 10 seconds to raise the temperature of the platen to 180 °C. Where the platen comprises ferrimagnetic particles of average diameter 3.5 micrometers dispersed in a matrix at about 5% by volume, the platen is placed in the center of the rectangular resonant cavity described above, and an alternating magnetic field of frequency 913.8 MHz is applied at a power level of 200 Watts for 55 seconds to raise the temperature of the platen to 180 °C. The time required to bond two thermoplastic urethane layers having a melting temperature of 160° C and a thickness of about 10 mils is about 0.25 mm when the platen is heated to 180 °C.

An advantage of the method of bonding or embossing thermoplastic layers of the present invention over prior art methods is reduced power consumption. For example, the heating of a platen comprising a fluoropolymer matrix dispersed with layered ferromagnetic flakes by exposure to an electromagnetic field requires only the power to generate the electromagnetic field, which is on the order of 100 to 500 Watts. Such power consumption is comparable to the power required to illuminate a single light bulb. In comparison, the power required to induction or resistance heat a conventional platen for bonding thermoplastic layers is about 1 to 25 kilowatts.

It will be understood that the exemplary embodiments described herein in no way limit the scope of the invention. Other modifications of the invention will be apparent to those skilled in the art in view of the foregoing description. These

descriptions are intended to provide specific examples of embodiments which clearly disclose the present invention. Accordingly, the invention is not limited to the described embodiments or to the use of the specific elements, dimensions, materials or configurations contained therein. All alternative modifications and variations which fall within the spirit and scope of the appended claims are included in the present invention.

Example

Platens were fabricated using various types of susceptor particles to compare their heating rates. Each of the platens tested was formed into the same shape, and tested under the same conditions.

One matrix material used to make the platens was a fluoropolymer sold by Dyneon Corp., St. Paul, MN under the trade designation FC-2174 Fluorel. The platens employing the fluoropolymer matrix were made by first mixing a composite consisting of 88% by weight, of the fluoropolymer, based on the total weight of the platen, 5% by weight of a calcium hydroxide powder, 2.5% by weight of a magnesium oxide powder, and 4.5% by weight of an ultrafine silica filler. The silica filler material was added to the fluoropolymer as a stiffening agent, and the calcium hydroxide and magnesium oxide powders were added to promote the curing process. When the composite is cured to form the final platen, the fluoropolymer releases acids. The calcium hydroxide and magnesium oxide powders act as acid acceptors to compensate for the release of acid by the fluoropolymer during curing.

A second matrix material used to make the platens was a polyethylene. Because the precise nature of the matrix material did not affect the heating rate of the platens, the heating rate measurements of the fluoropolymer-based platens could be reliably compared to the polyethylene-based platens.

After mixing the matrix material, the susceptor particles were then added to achieve the target volume loading values for each type of susceptor particle as is shown in Table 1. The corresponding matrix material used for each particle type is also shown in Table 1. The respective ingredients were then mixed in a

rubber mill or in a Braebender mixer until thoroughly blended. To form the mixtures into their final platen shape, the mixtures were compression molded for 15 minutes at 175°C. The compression molding step both formed the platen shape and cured the fluoropolymer and polyethylene composites.

The susceptor particles used are as listed in Table 1. The general classes of susceptor particles used were multilayered ferromagnetic flakes as described above, ferrite particles, and ferromagnetic powders. In particular, four different types of ferrite particles and two forms of an iron silicide powder (a ferromagnetic powder) were used as designated in Table 1. Each of the ferrites and iron silicide powders are commercially available from Steward, Inc., Chattanooga, TN under their respective trade designations as identified in Table 1.

The platens made using each of these susceptor particle types were separately exposed to a 913.8 MHz magnetic field inside the resonant cavity described above. A power level of 200 Watts was used. The temperature of the platen was measured as a function of exposure time to determine the heating rate of each platen under these conditions. The results were plotted as platen temperature in degrees C versus exposure time in seconds as shown in Figure 5. A separate curve was generated for each of the seven susceptor particle types used, each curve being labeled A-G corresponding to the labels in Table 1 below.

Table 1

Fig. 5 label	Type of susceptor particle	Matrix material	Loading % (by volume)
A	Multilayered ferromagnetic flakes	Fluorel	2.5
B	Steward Ferrite 73306	polyethylene	5
C	Steward Ferrite 73300	polyethylene	5
D	Steward Ferrite 72802	polyethylene	5
E	Steward Ferrite 73500	polyethylene	5
F	Steward Iron Silicide Powder 79100 (coarse)	polyethylene	5
G	Steward Iron Silicide Powder 79100 (fine)	polyethylene	5

The heating performance characteristics of each platen can be determined by reference to the plot in Figure 5. Heating performance can be described by two

factors: the rate at which the platen is heated at a given magnetic field frequency and a given power level, and the ultimate temperature attainable by the platen. As can be seen in Figure 5, both the heating rate and the ultimate temperatures of the platens using multilayer flakes as susceptor particles was superior to that of the platens using either ferrite particles or ferromagnetic powders. Thus, the multilayered flakes are the most preferred choice for susceptor particles under the defined heating conditions. Although the platens comprising ferrite particles did not heat as quickly as those comprising the multilayer flakes, the heat generated using the ferrite susceptors was sufficient to bond two 0.25 mm thick polyurethane films as described above. Thus, the ferrite particles are still an acceptable alternative for susceptor particles under the defined heating conditions. The platens comprising iron silicide powders heated even more slowly, and in the case of the fine iron silicide powder used, the platen was not heated sufficiently to bond two 0.25 mm thick polyurethane films.

According to the data shown in Figure 5, at a magnetic field frequency of 913.8 MHz and a power level of 200 Watts, platens comprising the multilayered flakes are preferred over platens comprising ferrite particles, and platens comprising ferrite particles are preferred over platens comprising iron silicide powders, given the susceptor particle loading volumes used as listed in Table 1.

It should be noted, however, that the heating performance of each of these platens may be improved if a higher volume loading of susceptor particles is used (for example, 5% rather than 2.5% for the multilayered flakes or 10% rather than 5% for the ferrite particles), if more power is applied (for example, 500 Watts rather than 200 Watts), or if a magnetic field of a different frequency is used. Indeed, each type of susceptor particle typically has an optimal frequency or frequency range for energy absorption, and thus heat generation, within the RF range. Thus, for improved heating performance, a frequency should be used that is within the optimal frequency range for the type of susceptor particles used.

WHAT IS CLAIMED IS:

1. A method for locally heating a work piece, comprising the steps of:

forming a platen (22) from a composite (10) comprising RF susceptor particles (12) dispersed in a non-metallic matrix (14);

applying an electromagnetic field to heat the platen (22) to a predetermined processing temperature; and

positioning the work piece in contact with the platen (22).

2. The method for locally heating as claimed in claim 1, wherein the matrix (14) is selected from the group consisting of epoxies, fluoroelastomers, polytetrafluoroethylene, phenolic resins and ceramics.

3. The method for locally heating as claimed in claim 1, wherein the susceptor particles (12) are selected from ferrimagnetic particles, ferromagnetic particles, and mixtures thereof.

4. The method for locally heating as claimed in claim 1, wherein at least a portion of the susceptor particles (12) are multilayer flakes (20), each flake comprising at least one layer pair, each layer pair comprising one crystalline ferromagnetic metal layer (16) adjacent to one dielectric layer (18), wherein the layer pairs form a stack of alternating ferromagnetic metal layers and dielectric layers.

5. An apparatus for locally heating a work piece, comprising:

a platen (22) formed from a composite (10) comprising a matrix (14) and susceptor particles (12) dispersed in the matrix (14);

a means for remotely applying an electromagnetic field to the platen; and

a means for positioning the work piece proximate to the platen.

6. The apparatus for locally heating as claimed in claim 5, wherein the matrix (14) is a fluoroelastomer.

7. The apparatus for locally heating as claimed in claim 5, wherein the susceptor particles (12) are selected from the group consisting of ferrimagnetic particles, ferromagnetic particles and mixtures thereof.

8. The apparatus for locally heating as claimed in claim 5, wherein at least a portion of the susceptor particles (12) are multilayer flakes (20), each flake comprising at least one layer pair, each layer pair comprising one crystalline ferromagnetic metal layer (16) adjacent to one dielectric layer (18), wherein the layer pairs form a stack of alternating ferromagnetic metal layers and dielectric layers.

9. A method for bonding a first sheet-like work piece to a second sheet-like work piece, comprising the steps of:

forming a substantially planar platen (22) from a composite (10) comprising a fluoroelastomer matrix (14) having dispersed therein ferromagnetic susceptor particles (12);

applying an electromagnetic field with a frequency of about 100 kHz to about 6000 MHz to heat the platen (22) to a predetermined bonding temperature;

positioning the first work piece adjacent the second work piece to form an overlapping work area; and

placing the platen (22) in contact with at least one of the first and second work pieces for a time and with a pressure sufficient to bond, in a predetermined portion of the work area, the first work piece to the second work piece.

10. A method for bonding a first thermoplastic film to a second thermoplastic film, comprising the steps of:

forming a substantially planar platen (22) from a composite (10) comprising a fluoroelastomer matrix (14) having dispersed therein susceptor particles (12) comprising multilayer flakes (20), each flake comprising at least one layer pair, each layer pair comprising one crystalline ferromagnetic metal layer (16) adjacent to one dielectric layer (18), wherein the layer pairs form a stack of alternating ferromagnetic metal layers and dielectric layers;

applying an electromagnetic field with a frequency of about 100 kHz to about 6000 MHz to heat the platen to a predetermined bonding temperature;

positioning the first film adjacent the second film to form an overlapping work area; and

placing the platen (22) in contact with at least one of the first and second films for a time and with a pressure sufficient to bond, in a predetermined portion of the work area, the first film to the second film.

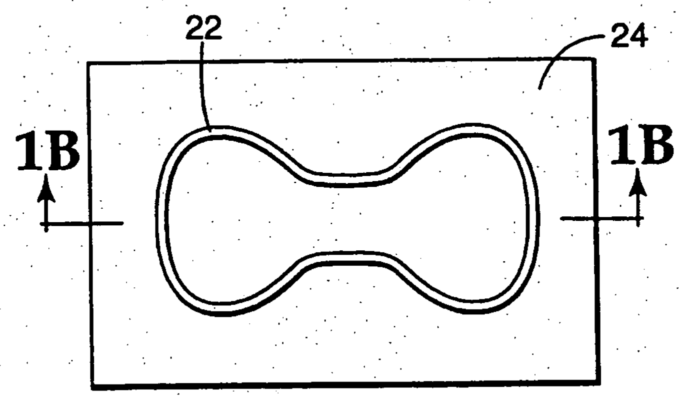


Fig. 1A

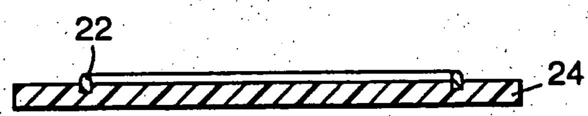


Fig. 1B

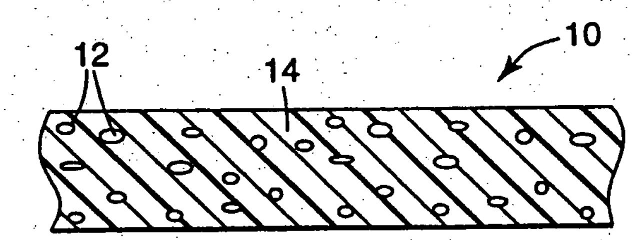


Fig. 2

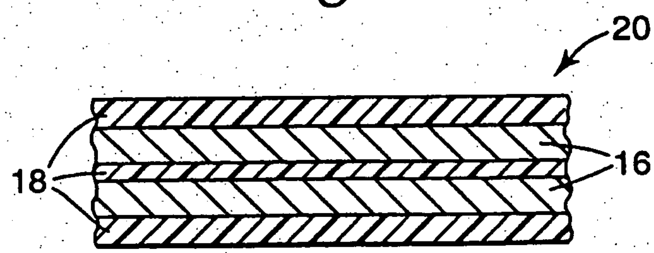


Fig. 3

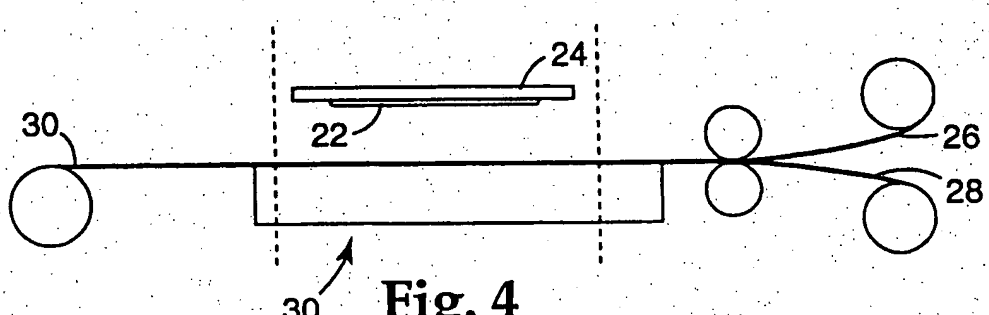
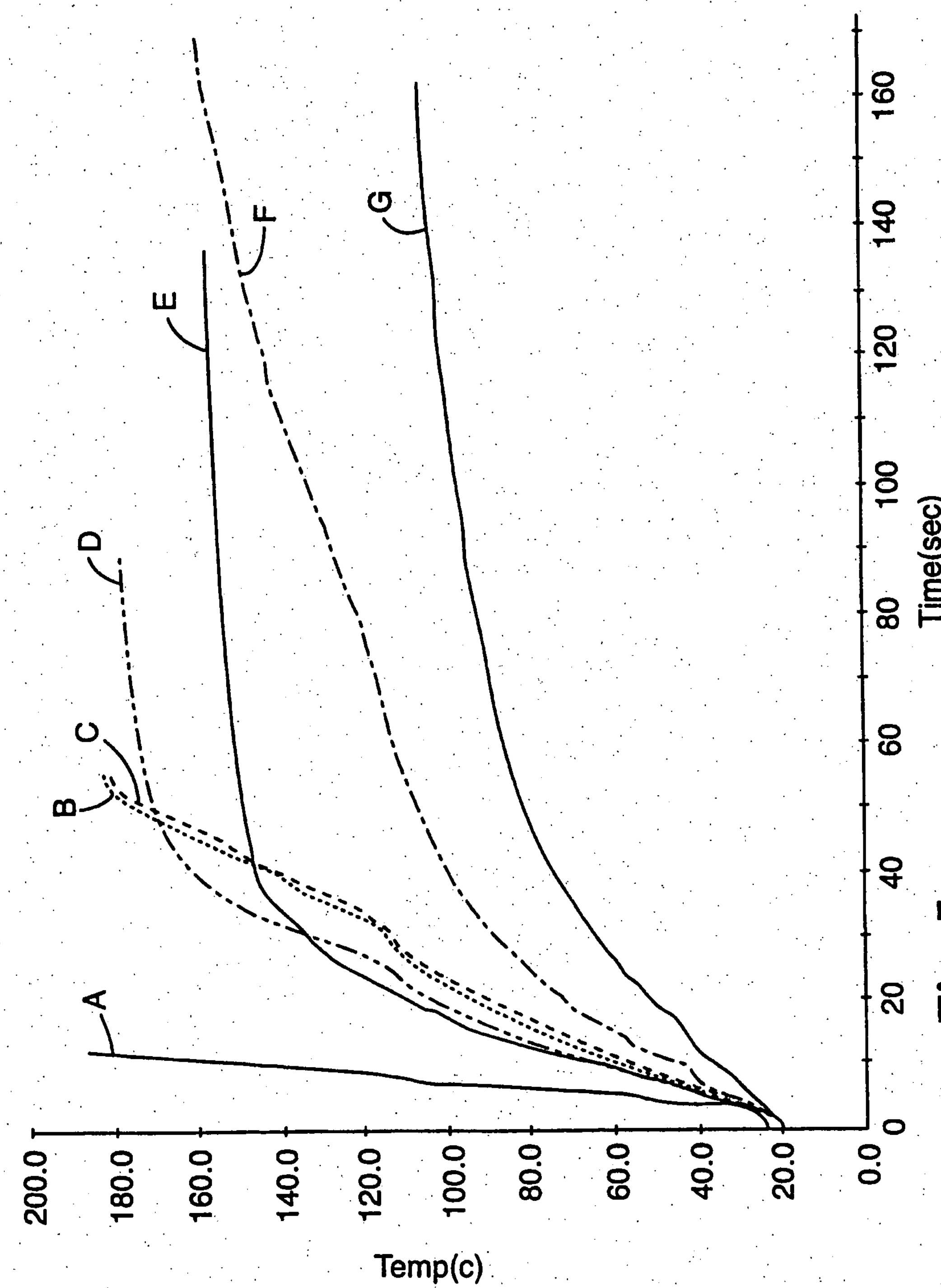


Fig. 4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20
40
60
80
100
120
140
160
A
B
C
D
E
F
G

Fig. 5

INTERNATIONAL SEARCH REPORT

Inter   nal Application No
PCT/US 97/20623

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H05B6/02 H05B6/10 B29C33/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H05B B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 587 098 A (MATSEN MARC R ET AL) 24 December 1996 see abstract; claim 1	1
A	US 3 791 906 A (FARKAS R) 12 February 1974	
A	WO 91 16800 A (METCAL INC) 31 October 1991	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
11 March 1998	17/03/1998
Name and mailing address of the ISA	**Authorized officer**
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Smet, F

INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/US 97/20623

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